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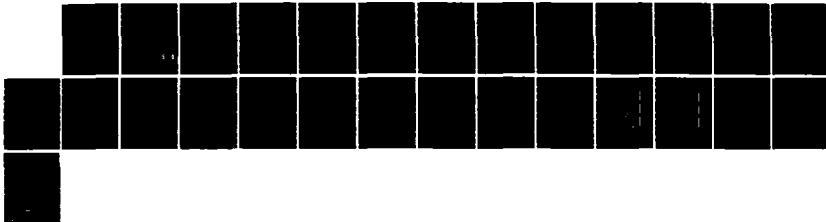
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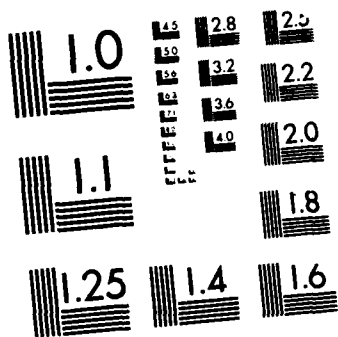
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Cooling Different Body Surfaces During Upper- and Lower-Body Exercise

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Running Head: Microclimate Cooling During Upper- and Lower-Body Exercise

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19. Abstract (cont'd)

change in rectal temperature (T_{re}) were observed with torso, thigh and upper arm cooling compared to cooling only the torso. Altering coolant temperature had no effect on changes in T_{re} but higher heart rates were observed with 26°C coolant temperature compared to 20°C. These data indicate cooling the surfaces of the upper arms during upper-body exercise provides no thermoregulatory advantage while cooling the thigh surfaces during lower-body exercise does provide a thermoregulatory advantage. The difference in the effectiveness of increasing cooling surface area may be related to the relatively small surface area of the arms or the greater ability of the thighs to make vasomotor adjustments to take advantage of improved conductive cooling.

ABSTRACT

The effect of varying the body surface area being cooled by a liquid microclimate system was evaluated during exercise/heat stress conditions. Six male subjects performed a total of six exercise (O_2 uptake, $1.2 \text{ l} \cdot \text{min}^{-1}$) tests in a hot environment (ambient temperature = 38°C , relative humidity = 30%) while dressed in a clothing ensemble having low moisture-permeability and high insulation (2.6 clo). Each subject completed two upper-body exercise tests: (a) with only the torso surface cooled; and (b) with the surfaces of both the torso and upper arms cooled (coolant temperature was 20°C for all upper body tests). Each subject also completed four lower-body exercise tests: (a) with only the torso surface cooled (coolant temperature = 20°C); (b) with only the torso surface cooled (coolant temperature = 26°C); (c) with torso, thigh, and upper arm surfaces cooled (coolant temperature = 20°C); (d) with torso, thigh, and upper arm surface cooled (coolant temperature = 26°C). During upper-body exercise, cooling the upper arms in addition to the torso had no effect on any measured parameter. During lower-body exercise, reductions ($P < 0.05$) in the sweat rate, heart rate and change in rectal temperature (T_{re}) were observed with torso, thigh and upper arm cooling compared to cooling only the torso. Altering coolant temperature had no effect on changes in T_{re} but higher heart rates were observed with 26°C coolant temperature compared to 20°C . These data indicate cooling the surfaces of the upper arms during upper-body exercise provides no thermoregulatory advantage while cooling the thigh surfaces during lower-body exercise does provide a thermoregulatory advantage. The difference in the effectiveness of increasing cooling surface area may be related to the relatively small surface area of the arms or the greater ability of the thighs to make vasomotor adjustments to take advantage of improved conductive cooling.

Key words: Heat stress, microclimate cooling, arm-crank exercise, treadmill exercise, temperature regulation, heat exchange.



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INTRODUCTION

Many occupations require workers to wear protective clothing such as flame retardant or chemical and radiological protective ensembles. The relatively impermeable materials used to construct these clothing systems limit the effectiveness of physiological mechanisms of heat dissipation, especially sweating. Thus, heat stress conditions due to environmental and metabolic factors are exacerbated and work performance is impaired (3,4). In some situations, work-rest cycles can alleviate heat-stress; however, this approach is often not sufficient. Microclimate cooling systems (cooling the environment immediately adjacent to the skin) have been developed and shown to be effective in alleviating heat stress and extending performance (15,16). The most effective microclimate cooling system would provide cooling to the entire body surface (17), but practical constraints in system design allow cooling of only limited areas of the body. Thus the question arises, how much and which body surface area should be cooled? Consideration must be given to the type of activity being performed since regional heat exchange during exercise is influenced by the skeletal muscle groups employed (2,13,19).

It has been shown that core temperature responses to exercise in temperate or hot environments are independent of the skeletal muscle group employed, but dependent on the metabolic rate elicited by the exercise (13,14). Thus, the core temperature response during upper- and lower-body exercise in air environments at equal levels of $\dot{V}O_2$ is the same; however, the local evaporative, radiative or convective heat exchanges differ between the two modes of exercise (13). In contrast, core temperature responses during upper- and lower-body exercise (same $\dot{V}O_2$) in water were observed to be different (19). Both the high convective heat transfer coefficient of water and differences in the surface area-to-mass ratio of the active muscle were considered to favor

heat loss during upper-body exercise in liquid environments (19). The present investigation attempted to apply these physiological observations (13,14,19) to a specific problem: the development of the optimal configuration of a liquid microclimate cooling system to alleviate heat stress associated with performing work with different muscle groups.

The purpose of the present investigation was to determine the effects of cooling varied body surface areas during upper- and lower-body exercise under heat-stress conditions. In addition, the effect of altering the temperature of the liquid coolant on physiological responses to exercise-heat stress was examined.

METHODS

Subjects and Experimental Design. Six male volunteers served as test subjects after being completely informed as to the risks and requirements of participation. Descriptive characteristics of the subjects (mean \pm S.E.) were age: 23 ± 1 yrs; height: 179 ± 3 cm; and weight: 77 ± 4 kg. Prior to experimental testing, the subjects were familiarized with all procedures. Also, maximal O_2 uptake ($\dot{V}O_2$ max) during both upper-body (arm-crank) and lower-body (treadmill running) exercise was determined. Additionally, all subjects participated in a heat-acclimation program in order to avoid the possibility that the subjects would become progressively heat-acclimated during the study. Each day the subjects walked ($1.34 \text{ m}\cdot\text{sec}^{-1}$) on a treadmill (5% grade) for 180 min (three repeats of 10 min rest, 50 min exercise) in a hot environment (ambient temperature (T_a) = 35°C dry bulb, relative humidity (rh) = 30%, windspeed (ws) = $0.45 \text{ m}\cdot\text{sec}^{-1}$). The subjects wore shorts, T-shirts, socks and tennis shoes during heat acclimation and maximal exercise testing sessions.

The subjects completed a total of six experimental heat-stress tests; each test was separated by a recovery period of 24-hours. Each test employed a

different combination of exercise mode and regional cooling configuration. The first four tests employed coolant chilled to 20°C (measured at the inlet to the vest), and the test combinations were: 1) upper-body exercise with torso cooling; 2) upper-body exercise with torso and upper-arm cooling; 3) lower-body exercise with torso cooling; 4) lower-body exercise with torso, upper-arm and thigh cooling. The two remaining heat stress tests repeated the lower-body exercise with torso and again with torso, arm and thigh cooling, but for these latter two tests the coolant temperature was 26°C. The order of presentation of the test combinations was randomized for each subject.

Each heat-stress test consisted of a 150-min exposure (three repeats of 10-min rest, 40-min exercise) to a hot environment ($T_a = 38^\circ\text{C}$ db, 10% rh). Exercise consisted of either arm cranking or treadmill walking; both were performed at absolute intensities (40 W, $1.27 \text{ m}\cdot\text{sec}^{-1}$ at 0% grade, respectively) selected to elicit the same submaximal $\dot{V}O_2$ (target = $1.2 \text{ l}\cdot\text{min}^{-1}$). With the exception of the different cooling garment configurations, the subjects were dressed the same for each heat-stress test: cotton socks, cotton undershorts and T-shirt, nylon-cotton coveralls, ballistic armor vest, leather boots, cotton glove-liners, charcoal impregnated chemical protective overgarment, butyl gloves, butyl boot covers, and vehicle crewman's helmet. The cooling garment system was worn over the underwear and beneath the coveralls. The estimated clo value for the entire clothing ensemble was 2.6.

Microclimate Cooling Systems. A liquid microclimate cooling system was used to cool the different skin surfaces. The cooling system was developed by the U.S. Army Natick Research, Development, and Engineering Center, and has been described in detail elsewhere (1). For cooling the torso surface, a vest constructed of three panels was worn. One panel covered the entire back, and two panels joined by a zipper covered the front. The panels consist of two

polyurethane coated nylon layers sealed such that flow channels are created within the layers. The vest covered approximately 17% of the body surface area. To provide cooling to both torso and upper arms, a similar vest was used which also includes panels to cover the biceps area thereby increasing the total surface area covered by an additional 6%. This latter vest also has connections which allow the addition of two panels to cover the thigh area, allowing cooling of torso, arm and thigh surfaces. Use of the thigh panels increases the surface area cooled by an additional 17%. Design of the system does not allow use of the thigh panels without the arm panels. The garments are connected to a cooling unit by an umbilical tube threaded through openings in the outer garment. For the torso vest, the coolant enters the garment at the collar, flows to the chest, next to the back, and then returns to the cooling unit. The torso/arm cooling garment uses the same basic flow pattern except that the arm panels are inserted in series between the front and back panels. When the thigh panels are added to this system the flow pattern is altered to circulate the coolant from the collar to the thighs and then to the chest. The liquid coolant is chilled to the desired temperature and is circulated through the garment at $380 \text{ ml} \cdot \text{min}^{-1}$. The coolant is a mixture of propylene glycol (10%) and water.

Procedures. Maximal O_2 uptake was determined using a continuous progressive intensity protocol for both treadmill (6) and arm crank exercise (12). For arm-crank exercise, $\dot{\text{V}}\text{O}_2 \text{ max}$ was defined as the highest $\dot{\text{V}}\text{O}_2$ attained. All arm-crank exercise was performed at a crank rate of 70 rpm. For treadmill running, the criteria for $\dot{\text{V}}\text{O}_2 \text{ max}$ was plateau of $\dot{\text{V}}\text{O}_2$ with an increase in exercise intensity.

During the maximal exercise tests, $\dot{\text{V}}\text{O}_2$ was measured over consecutive 15-sec intervals with an automated system (Sensormedics Horizon MMC). During the heat stress tests, $\dot{\text{V}}\text{O}_2$ was determined by open-circuit spirometry; expired

air was collected over a two-min interval between 18 and 20-min of each of the three exercise bouts of the heat-stress tests, and volume, O_2 and CO_2 concentration of the timed gas collection was measured. The ECG was continuously monitored during the maximal exercise and heat-stress tests using chest-electrodes (CM5 placement) and the heart rate was calculated from the ECG. Rectal temperature (T_{re}) was measured continuously during the heat-stress tests using a thermister inserted 10 cm beyond the anal sphincter. Sweat rate was calculated by the change in pre- and post-test nude weight corrected for water intake (water intake was ad libitum during the tests). At the 30th min of each exercise bout during the heat-stress test, the subjects were asked to rate their perception of thermal sensation using the rating scale shown in Figure 1.

(Figure 1 about here)

Statistical Analyses. Multifactor analysis of variance (ANOVA) was used to determine if factor main effects or interactions were significant. Separate ANOVA was performed for each exercise mode. For the upper-body exercise heat-stress tests, the factors compared were "exercise bout" (i.e. first, second, or third) and "surface area cooled" (i.e. torso or torso and arms). For the lower-body exercise heat-stress tests, the factors compared were "exercise bout," "surface area cooled" (i.e. torso or torso, arms, and thighs) and "coolant temperature" (i.e. 20 or 26°C). In the event that ANOVA indicated significant main or interaction effects, Tukeys critical difference was calculated and used to locate significant differences between means. In addition, responses to upper- and lower-body exercise during those tests employing torso cooling alone (with coolant temperature of 20°C) were compared using the student T test. Unless otherwise noted, data are reported as mean \pm SE. The level for statistical significance was set at $P < 0.05$.

RESULTS

Heat Acclimation Program. The subjects were judged to be fully acclimated after 4 days. There were no significant differences in T_{re} or HR at the end of the acclimation sessions between the first and fourth day.

Maximal Exercise Tests. During maximal lower-body exercise, $\dot{V}O_2$ was $4.45 \pm 0.32 \text{ l}\cdot\text{min}^{-1}$ and HR was $201 \pm 4 \text{ b}\cdot\text{min}^{-1}$. During maximal upper-body exercise, $\dot{V}O_2$ was 2.76 ± 0.29 and HR was $198 \pm 3 \text{ b}\cdot\text{min}^{-1}$.

(Table 1 About here)

Heat-Stress Tests: Upper-Body Exercise. Table 1 shows the heart rate and $\dot{V}O_2$ responses to upper-body exercise. There were no significant effects on either $\dot{V}O_2$ or heart rate during the upper-body tests due to exercise bout or amount of surface area cooled. Averaged over all upper-body tests, $\dot{V}O_2$ was $1.20 \pm 0.05 \text{ l}\cdot\text{min}^{-1}$ (~44% upper-body $\dot{V}O_2$ max) and HR was $128 \pm 10 \text{ b}\cdot\text{min}^{-1}$.

(Figure 2 About here)

Changes in T_{re} (relative to the initial) during each rest/exercise cycle of the two upper-body exercise heat stress tests are shown in Figure 2. There was no effect of the amount of surface area cooled on T_{re} changes during upper body exercise. The T_{re} rose during exercise and fell during rest, but not until the completion of the third exercise bout was T_{re} significantly higher ($p < 0.004$, 0.42°C) than at the beginning of the test. With torso cooling, sweat rate ($370 \pm 34 \text{ g}\cdot\text{m}^{-2}\cdot\text{h}^{-1}$) was not significantly different from that with torso and upper arm cooling ($330 \pm 23 \text{ g}\cdot\text{m}^{-2}\cdot\text{h}^{-1}$). The subjective ratings of thermal sensations indicated that the subjects felt progressively hotter ($p < 0.02$) with each exercise bout (5.0 ± 0.2 , 5.2 ± 0.2 and 5.4 ± 0.3 , respectively) of the heat-stress test, but there was no effect ($p < 0.34$) of surface area cooled on the thermal sensations.

(Table 2 About here)

Heat-Stress Tests: Lower-Body Exercise. The $\dot{V}O_2$ and heart rate during lower-body exercise heat stress tests are shown in Table 2. There were no significant differences in $\dot{V}O_2$ during lower-body exercise due to either the amount of surface area cooled or the coolant temperature. Furthermore, there were no differences in $\dot{V}O_2$ between exercise bouts. Averaged over all, $\dot{V}O_2$ was $1.20 \pm 0.06 \text{ l} \cdot \text{min}^{-1}$ ($27\% \dot{V}O_{2 \text{ max}}$ during lower-body exercise). In contrast, heart rate during lower-body exercise was significantly reduced ($\sim 8 \text{ b} \cdot \text{min}^{-1}$, overall) by cooling the additional surface areas of the upper arms and thighs as compared to cooling only the torso surface. ANOVA also indicated an interaction effect between the two factors "coolant temperature" and "exercise bout". There was no effect of coolant temperature on heart rate during the first and second lower-body exercise bout; however with 26°C coolant temperature, heart rate during the third exercise bout was higher compared to corresponding measurements made with 20°C coolant temperature.

(Figure 3 About Here)

Coolant temperature had no effect on changes in T_{re} during the lower-body exercise heat-stress tests, therefore the data have been pooled in Figure 3 to show the effect of the amount of surface area cooled on changes in T_{re} during lower-body exercise. Cooling the torso, arm and thigh surfaces resulted in smaller ($p < 0.04$) increments in T_{re} during exercise compared to cooling only the torso; changes in T_{re} during rest periods were not affected by cooling additional surface area. The T_{re} increased ($p < 0.001$) during the first and again during the second exercise period, with no additional increment during the third exercise period. Sweat rates were also reduced ($p < 0.02$) when torso, arm and thigh surfaces were cooled ($318 \pm 21 \text{ g} \cdot \text{m}^{-2} \cdot \text{h}^{-1}$) as compared to cooling only the torso ($383 \pm 31 \text{ g} \cdot \text{m}^{-2} \cdot \text{h}^{-1}$), but there was no effect of coolant temperature on sweat rate. The subjective ratings of thermal sensations indicated that, like upper-

body exercise, there was no effect ($P < 0.42$) of cooling the torso, arms and thighs on perceptions as compared to cooling the torso alone. Furthermore, there were no differences ($P < 0.09$) between the three bouts in thermal sensations reported. However, higher ($p < 0.02$) ratings (e.g. hotter) were reported when coolant temperature was 26°C (5.5 ± 0.2) as compared to ratings reported with coolant temperature of 20°C (5.0 ± 0.2).

Upper-Body Versus Lower-Body Exercise. There was no difference in $\dot{V}\text{O}_2$ between upper-body exercise with only torso cooling (20°C coolant temperature) compared to lower-body exercise with only torso cooling. Similarly, the sweat-rate and changes in T_{re} during those tests were not different. There was a trend for lower heart rates during upper- than lower-body exercise but the difference was not significant ($p < 0.10$). Finally, subjective ratings of thermal sensations reported during upper-body exercise with only torso cooling were not different from ratings reported during lower-body exercise with only torso surface cooling.

DISCUSSION

This study investigated the thermoregulatory effects of cooling different amounts of body surface area during exercise-heat stress. It was hypothesized that the effect of increasing the amount of body surface area being cooled would be different for upper- as compared to lower-body exercise. It has been previously shown that upper- and lower-body exercise performed at the same metabolic rate in a hot environment elicits similar changes in core temperature; however, the primary avenues of heat exchange are different (13). In hot environments, dry heat exchange ($R+C$, radiative and convective) of the torso is greater with upper-body exercise than with lower-body exercise; lower-body exercise elicits greater ($R+C$) or evaporative cooling at the legs, depending on which of those avenues is favored by the ambient environmental conditions (13).

Thus, increasing the surface area cooled to include the thighs in addition to the torso might be advantageous in the case of lower-body exercise, while cooling both torso and upper arms during upper-body exercise might have little effect over cooling only the torso surface. However, Toner et al. (19) studied thermoregulatory responses to upper- and lower-body exercise of the same metabolic intensity in an environment (20°C water) which maximized the potential for conductive heat loss. In that investigation, core temperature fell more and skin heat flow was greater during upper- compared to lower-body exercise. The findings of Toner et al. (19) suggest that providing conductive cooling to both arms and torso might be advantageous during upper-body exercise as opposed to cooling only the torso.

During upper-body exercise, heart rate, O₂ uptake, sweat rate and changes in core temperature were not affected by increasing the amount of body surface area cooled. Arm-crank ergometry requires utilization of muscle groups in the chest, shoulder, and back in addition to the arms (14). In fact, of the arm muscles involved, probably only the triceps participates to any major extent. Therefore most of the active muscle mass was effectively cooled when the torso vest alone was worn. Despite the large surface area-to-mass ratio of the triceps, cooling the upper arms only increases the total surface area for cooling from 17 to 23% and has little effect on the total volume of active muscle being cooled. It might be argued that a 6% increase in the body surface available for cooling is too little to have any effect on thermal strain. Cooling the head, however, increases the surface area for cooling by a similar (~8%) amount, yet head cooling has been shown to significantly reduce heat strain (8). The lack of an effect of arm cooling on responses to upper-body exercise is consistent with the data of Sawka et al. (13) which indicated that the arms may not be capable of the vasomotor adjustments needed to take advantage of improved conductive heat transfer conditions.

Increasing the amount of surface area being cooled from 17% (torso) to 40% (torso, arms and thighs) did alter the responses to lower-body exercise. Ideally, the effect of cooling the torso and thighs (without upper arms) should have been compared to cooling the torso alone, but suit design precluded that cooling configuration. Thus the question is raised as to whether cooling the upper arms during lower-body exercise contributed significantly to the overall effect of increased surface area for cooling. This seems unlikely since the upper-arm muscles are nearly inactive during lower-body exercise, and the upper arms constitute a small amount of the total surface area covered when torso, thigh and arm cooling was employed (7). Furthermore, it has been shown that dry heat exchange of the arms is the same for upper- and lower-body exercise of the same metabolic rate (13). Therefore, since cooling the upper arms had no effect on thermoregulatory responses to upper-body exercise, there is little reason to believe that upper-arm cooling would affect thermoregulatory responses to lower-body exercise.

The microclimate system was more effective in alleviating heat stress during lower-body exercise when the surface area for cooling was increased to include the thighs. Heart rates, sweat rates and changes in core temperature were all lower compared to when only the torso was cooled. The improved cooling was probably due to the large increase in amount of active muscle available for conductive heat transfer. Virtually none of the active muscle is cooled when only the torso surface is covered. The legs have a greater capacity than the arms to make adjustments in both sweating and vasomotor responses to optimally match local heat transfer to environmental conditions (13). Therefore, it is reasonable to speculate that the efficacy of an evaporative microclimate system would also be improved by cooling the thighs during lower-body exercise.

The effect of altering coolant temperature was studied only during lower body exercise. Raising coolant temperature from 20 to 26°C had no effect on sweat rate or changes in core temperature during the heat stress tests; however, heart rates were higher with the warmer coolant, but not significantly until the end of the third exercise bout. Since sweating was unchanged, evaporative heat loss was probably also the same. With the 26°C coolant, skin temperatures would be expected to be higher than with 20°C coolant, and cutaneous venous vascular tone would be decreased producing increased venous volume (9,10). A greater increment in cutaneous venous volume during exercise with the 26°C coolant is likely to have facilitated heat transfer between the skin and the microclimate system enabling core temperature changes to be the same as with 20°C coolant. However, the relatively greater skin blood volume would be associated with progressively higher heart rates in order to continue to maintain cardiac output constant as cutaneous vascular volume becomes greater (11). These findings suggest that in situations where cooling capacity of a microclimate system is limited (e.g. backpack type systems), thermal strain during work can still be alleviated, but at the possible expense of greater cardiovascular strain.

Coolant temperature was more important than the amount of surface area cooled for perception of thermal sensations during exercise-heat stress. Altering the surface area being cooled had no effect of the subjective ratings of thermal sensation reported during either mode of exercise. This was not surprising for upper-body exercise since core temperatures were also not affected. However, during lower-body exercise core temperatures were systematically reduced when cooling surface area was increased. Possibly, the perception of thermal sensations cannot discern differences in core temperature as small as 0.2°C. Alternatively, core temperature may contribute little to the perception of

thermal sensations. Even though coolant temperature had no effect on T_{re} , lower (cooler) sensations were reported when the coolant temperature was 20°C, in comparison with thermal sensations reported with 26°C. Although skin temperatures were not measured, higher T_{sk} would be expected with warmer coolant. Skin temperature probably provides a more important cue for perception of thermal sensation than core temperature (5).

In summary, the results of this investigation indicate that increasing the surface area covered by a conductive microclimate cooling system to include the upper arms imparts no advantage for cooling during upper-body exercise in the heat compared to cooling the torso alone. However, during lower-body exercise in the heat smaller changes in core temperature and lower sweat rates are observed when surfaces of the thighs are cooled in addition to the torso surfaces. The difference in the effect of increasing surface area for cooling is due to the small surface area of the arms compared to the thigh or, probably more likely, due to a greater ability of thighs to make vasomotor adjustments to take advantage of increased conductive cooling.

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FIGURE LEGENDS

Figure 1. Rating scale used by subjects to report thermal sensations.

Figure 2. Effect of cooling different skin surface areas on changes in rectal temperatures (ΔT_{re}) with rest and upper-body exercise ($\dot{V}O_2 \approx 1.2 \text{ l}\cdot\text{min}^{-1}$) under heat stress conditions.

Figure 3. Effect of cooling different skin surface areas on changes in rectal temperature (ΔT_{re}) during lower-body exercise ($\dot{V}O_2 \approx 1.2 \text{ l}\cdot\text{min}^{-1}$) under heat stress conditions.

THERMAL SENSATIONS

0.0 UNBEARABLY COLD

0.5

1.0 VERY COLD

1.5

2.0 COLD

2.5

3.0 COOL

3.5

4.0 COMFORTABLE

4.5

5.0 WARM

5.5

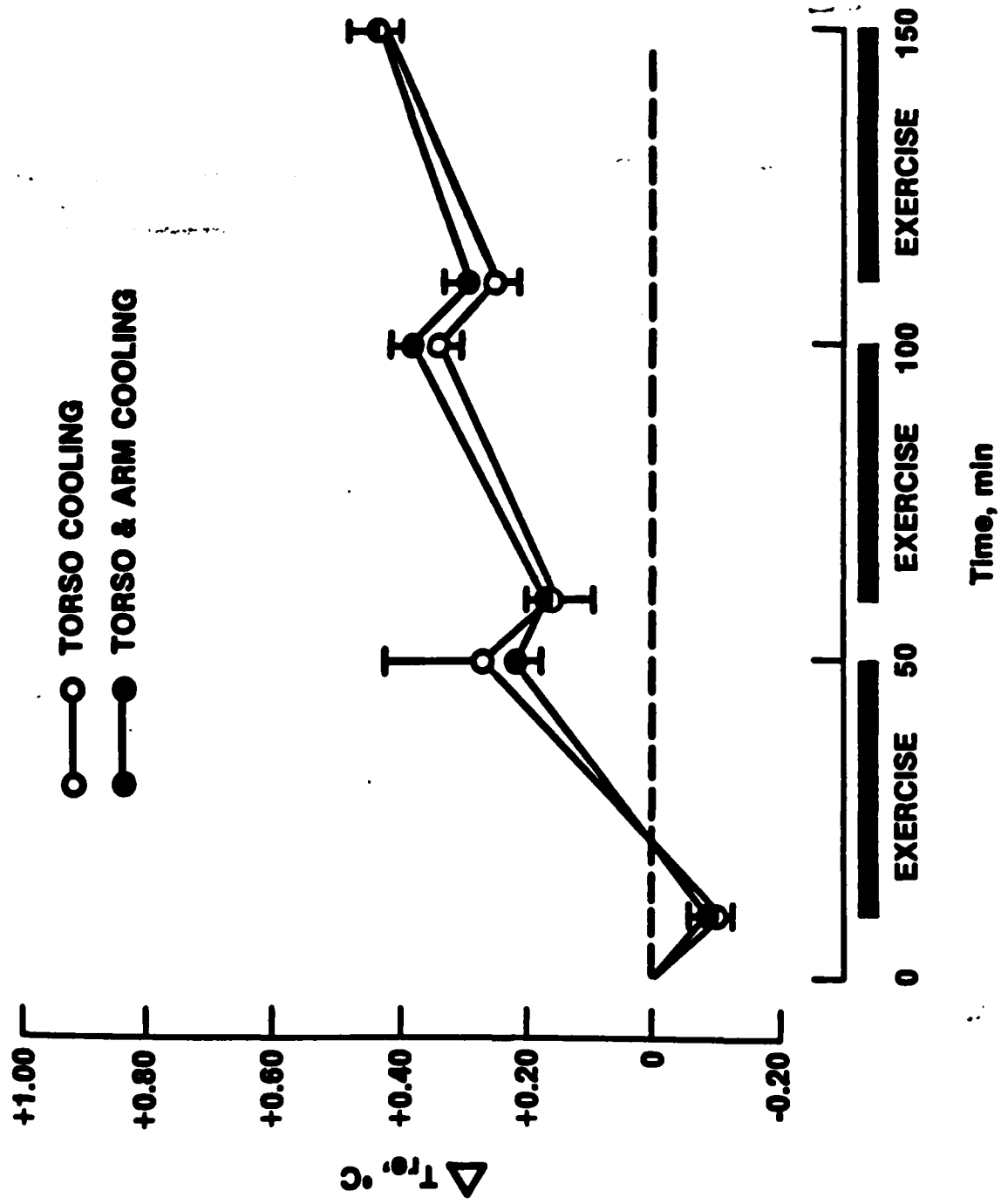
6.0 HOT

6.5

7.0 VERY HOT

7.5

8.0 UNBEARABLY HOT



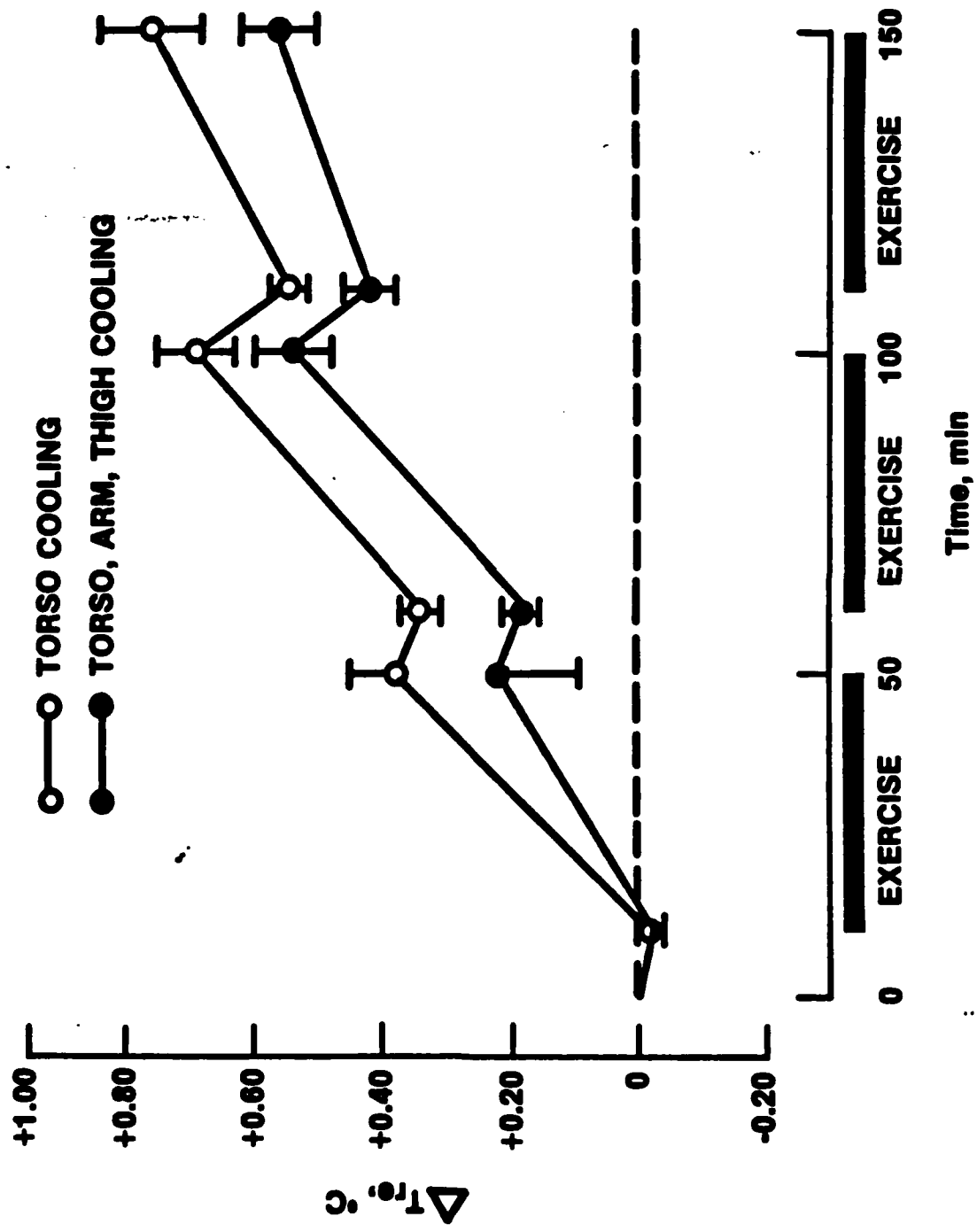


Table 1. Heart rate and O₂ uptake during upper-body exercise.

Surface Area Cooled (A)		Torso			Torso, Arms			Main Effect	Factor Interaction
Exercise Bouts (B)		1	2	3	1	2	3	A	B
HR, b·min ⁻¹									
		124±10	131±11	131±10	124±10	127±11	134±10	NS	NS
		1.16±0.04	1.21±0.05	1.22±0.04	1.17±0.01	1.18±0.03	1.27±0.06	NS	NS
VO ₂ , l·min ⁻¹									
		124±10	131±11	131±10	124±10	127±11	134±10	NS	NS
		1.16±0.04	1.21±0.05	1.22±0.04	1.17±0.01	1.18±0.03	1.27±0.06	NS	NS

Values represented mean ±SE (N=6). Heart rate (HR) was measured during the 50th and oxygen uptake (VO₂) during the 18th to 20th min of each exercise bout.

Table 2. Heart rate and O₂ uptake during lower-body exercise.

Coolant Temperature (A)	Surface Area Cooled (B)			Torso			Torso, Arms, Thighs			Main Effects			Factor Interactions
	Exercise Bout (C)			1	2	3	1	2	3	A	B	C	
	HR, b·min ⁻¹												
20°C				119±7	122±11	123±11	112±6	112±7	118±6	NS	Torso > Torso, Arms, Thighs*	NS	AXC**
26°C				116±9	128±11	132±11	113±7	119±7	123±10				
	$\dot{V}O_2$, l·min ⁻¹												
20°C				1.17±0.06	1.23±0.07	1.19±0.05	1.20±0.07	1.22±0.08	1.23±0.07	NS	NS	NS	NS
26°C				1.16±0.05	1.18±0.06	1.21±0.06	1.21±0.06	1.22±0.07	1.23±0.06				

Values represent mean ± SE (N=6). *Significant at P < .05; ** significant at p < 0.005. Heart rate (HR) measured during the 50 th min, and O₂ uptake ($\dot{V}O_2$) measured from 17 to 19th min of each exercise bout.

END

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